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**UNIVERSIDADE ESTADUAL DE CAMPINAS**

**FACULDADE DE ODONTOLOGIA DE PIRACICABA**

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Orientador: Prof. Dr. Francisco José de Souza Filho

# "Comparação da longevidade de sistemas rotatórios de níquel-titânio utilizando uma nova plataforma de análise matemática (M.A.P.E.R.)"

Tese de Doutorado apresentada à Faculdade de Odontologia de Piracicaba da UNICAMP para obtenção do título de doutor em clínica odontológica, área de endodontia.

Doctorate Thesis presented to the Piracicaba Dental School of the University of Campinas to obtain the Ph.D grade in Clinical Dentistry, Endodontics area.

Este exemplar corresponde à versão final da
Tese defendida pelo aluno, e orientada pelo
Prof. Dr. Francisco José de Souza Filho

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Prof. Dr. ALEXANDRE AUGUSTO ZAIA

Prof. Dr. RICARDO FERREIRA

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*Aos meus **Pais**, de quem sinto falta constantemente, exemplos de integridade, trabalho, educação, bondade e felicidade. Os quais formaram, em longos anos, a pessoa que sou hoje.*

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# *Resumo*

Apesar de a instrumentação mecanizada agregar velocidade e qualidade ao tratamento endodôntico, a não utilização rotineira da mesma pelos endodontistas se deve, em parte, ao custo proveniente das trocas constantes de limas, na intenção de prevenir as fraturas que acometem os sistemas de instrumentação rotatória. Assim, no intuito de minimizar esse problema, torna-se necessário o desenvolvimento de sequências e/ou sistemas que permitam uma margem de segurança maior em relação à fratura. No Capítulo 1 deste estudo, o objetivo foi comparar 15 sistemas de instrumentação rotatória através de um método matemático desenvolvido pelo autor, utilizando o programa Microsoft Excel. Nomeado de “Plataforma de Análise Matemática da Taxa de Alargamento de Canais Radiculares” (M.A.P.E.R.), esse modelo matemático foi usado para calcular a taxa de alargamento, a força e as pressões de cisalhamento atuantes em cada meio milímetro dos instrumentos de todos os sistemas testados, auxiliando na criação de uma nova sequência seguindo a melhor distribuição de tensões possível (nomeada de RS6, Rotatório com Segurança utilizando 6 instrumentos), a qual, servirá como parâmetro de comparação. Nesta plataforma, foram inseridos dados de formato, sequência, penetração e torque de cada instrumento, sendo possível assim, calcular essas tensões exercidas em cada um, além de identificar os mais susceptíveis à fratura. Então, 350 molares superiores e inferiores, com curvaturas de raízes até 35º, foram instrumentados por 8 jogos, todos apenas da nova sequência RS6, avaliando a longevidade dos instrumentos nesta nova técnica. A sequência RS6, desenvolvida pelo autor com instrumentos K3 e reduzida ação de forças e pressões de cisalhamento, alcançou uma média de 116,1 condutos instrumentados até a ruptura, corroborando com os valores da plataforma. Analisando os resultados, podemos concluir que a plataforma matemática foi capaz de simular as forças e pressões envolvidas no funcionamento de cada lima em todas as sequências testadas. No Capítulo 2, um método *in vitro* em dentes humanos extraídos foi utilizado. A nova sequência foi então comparada à outras duas já utilizadas na plataforma matemática (ProTaper e Prodesign), em 200 molares, até a fratura de todos os instrumentos em duplicata. O número de condutos instrumentados por cada lima foi anotado e comparado com as informações calculadas pela plataforma. Na maioria dos casos, a separação ocorreu próxima do ponto de maior concentração de forças nos instrumentos. A sequência RS6, recém projetada, apresentou novamente os melhores resultados, quando comparada às outras duas, com uma média de 110,0 (a) condutos até a fratura, contra 78,5 (b) da ProDesign e 46,6 (c) da ProTaper ($p<0,05$). Concluindo, a sequência RS6, permitiu a reutilização dos instrumentos com grande segurança, protelando a fratura dos mesmos.

Palavras-chave: Instrumentação Rotatória, Fratura, Níquel-Titânio

# *Abstract*

The rotary instrumentation adds speed and quality to the endodontic treatment; however it is not routinely used. The endodontists are cautious on having the mechanized instrumentation as a resource, due to the cost of constant file reposition that is necessary to avoid the fractures that the systems constantly suffer while using this process. Thus, it is important to develop sequences and/or systems that allow a greater safety margin regarding these fractures. The aim of the first part of this study is to make the comparison of 15 rotary instrumentation systems through a mathematical method, which uses the Microsoft Excel program, developed by author. The mathematical model - named "Mathematical Analysis Platform of Enlargement Rate" (M.A.P.E.R.) - was used to calculate the rate of enlargement, strength and shearing pressure exerted in each half millimeter of the instruments in each one of the tested systems, which aided the creation of a new sequence - named RS6 (Rotary with Safety using 6 files) - that follows the best stress distribution as possible; hence, the RS6 became a benchmark. In this platform, we inserted the data of the shape, sequence, penetration and torque of each instrument, so it was possible for us to calculate the stresses exerted on each of the data and, thereby, identify the ones that are most likely to fracture. Then, to assess the longevity of the instruments using this new technique, 350 maxillary and mandibular molars with until 35° degrees of root canal curvatures were instrumented by 8 matches of this new RS6 sequence. The new developed sequence, RS6 with K3 files, presented the action of forces and shearing pressures reduced, and reached an average of 116.1 root canals instrumented until rupture, which corroborates with the values of the platform. Analyzing the results, we can conclude that the mathematical platform was able to simulate the forces and pressures involved in the functioning of each file, in all the sequences tested. In the second part of this study, we used an in vitro method on extracted human teeth. The new sequence was then compared to the other two previously used in the mathematical platform (ProTaper and ProDesign) in 200 molars, until the fracture of all instruments in duplicate. The number of root canals instrumented by each file was recorded and compared to the information calculated by the platform. In most instances, the separation occurred near the point of highest concentration of forces in the instruments. Once again, the newly designed sequence, RS6, showed the best results when compared to the other two. With an average of 110.0 (a) root canals until fracture, counter 78.5 (b) from the ProDesign and 46.6 (c) from the ProTaper ($p < 0.05$). In conclusion, the sequence RS6 allowed the reuse of the instruments with great safety, avoiding their fracture.

Key-words: Rotary Instrumentation, File Fracture, Nickel-Titanium

# *Sumário*

# *Introdução*

O preparo químico-mecânico endodôntico tem se mostrado muito importante para a desinfecção dos canais radiculares, após o qual, a obturação tridimensional tem como objetivo impedir a recolonização bacteriana, isolando as bactérias residuais dentro dos túbulos dentinários (Vivacqua-Gomes *et al.,* 2005).

Uma grande evolução nessa fase de limpeza e modelagem dos condutos foi a instrumentação mecanizada rotatória, que permite finalizar os preparos com mais rapidez, manutenção do comprimento de trabalho e menor transporte dos condutos, quando comparada às limas flexíveis manuais (Schafer, 2001). Peru *et al.* (2006) concluíram, por exemplo, que os sistemas rotatórios de Níquel-Titânio (NiTi) GT e ProTaper têm preparado canais radiculares mais rápido e com menos erros processuais do que as técnicas manuais, agregando importantes valores para a adesão a esses sistemas.

Praticamente não existem diferenças em relação à limpeza de canais radiculares entre as técnicas mecanizadas em comparação com as manuais, como mostram os autores Prati *et al.* (2004), que não encontraram diferenças em relação à remoção de detritos e smear layer, bem como Jardine & Gulabivala (2000), que alcançaram preparações semelhantes entre as instrumentações manual e rotatória. Alguns autores, como Ahlquist *et al.* (2001), mostraram inclusive uma melhor limpeza no terço apical utilizando limas manuais de aço inoxidável em relação ao sistema rotatório ProFile.

Esse preparo mecanizado tem sido importante na clínica endodôntica, tornando o tratamento mais fácil e rápido. No entanto, o grande problema em instrumentação rotatória é a fratura inesperada dos instrumentos, o que dificilmente acontece com limas manuais, segundo Schafer & Schlingemann (2003).

Duas são as condições responsáveis pela fratura dos instrumentos. A fadiga cíclica flexural ocorre principalmente ao rotacinar os instrumentos em secções curvas do conduto, e a fadiga torsional, que ocorre ao apreender a ponta do instrumento em rotação no interior do conduto. Esta última podendo acontecer em todos os tipos de canais, mesmo nos retos. Essa separação dos instrumentos, causada por torção ou fadiga à flexão, tem preocupado os endodontistas e, ainda representa um grande problema na adoção da Endodontia rotatória (Wei *et al.*, 2007).

Já foi demonstrado que a resistência à fadiga cíclica diminui quando os instrumentos são utilizados repetidamente em comparação com os novos (Fife *et al.*, 2004), por isso, vários autores testaram modelos para entender melhor esse comportamento mecânico dos instrumentos, demonstrando até 14 % de fratura dos instrumentos descartados, mesmo com uma limitação do número de uso dos mesmos (Cheung *et al.,* 2007). Isso indica um índice muito grande de separações, que podem comprometer seriamente o tratamento endodôntico, visto a grande dificuldade para a remoção ou passagem desses fragmentos (Shen *et al.*, 2004).

Um fator também importante na separação desses instrumentos é a força e o torque aplicado às limas. Ambos podem apresentar grandes variações, dependendo da curvatura radicular e do alargamento prévio do conduto, segundo Peters *et al.* (2003). O controle do torque aplicado à instrumentação através de motores elétricos, bem como a patência prévia, demonstram uma grande redução no índice de fraturas, como descreveram Zarrabi *et al.* (2010). Isso mostra como a sequência de limas utilizadas pode assumir um ponto de grande importância na longevidades desses instrumentos. De acordo com o alargamento prévio, as limas subsequentes sofrerão distribuições de força diferentes ao longo de suas espiras, provocando distorções ou separações (Peters *et al.*, 2003).

Melo *et al.* (2008) estudaram esses modos de fratura, e demonstraram que as limas podem rotacionar 700 vezes até a separação, dependendo do raio de curvatura. Considerando 10 segundos em cada utilização clínica, os instrumentos de menor calibre poderiam ser utilizados até 26 vezes em curvaturas graves, um valor surpreendente, mesmo para limas mais delgadas (Whipple *et al.,* 2009).

Essa longevidade vai depender muito do tipo de instrumento estudado. Alguns instrumentos apresentam reconhecidas capacidades de flexibilidade, como a Twisted File. Essas características auxiliam na resistência, quando utilizados em curvaturas severas (Rodrigues *et al.,* 2011; Bhagabati *et al.*, 2012).

É conhecido também, que o desenho das limas pode representar uma grande mudança em suas características mecânicas (Zhang *et al.,* 2010; Melo *et al.*, 2008; Cheung & Darvell, 2007; Park *et al.,* 2010; Viana *et al.*, 2010). Tripi *et al.* (2006) mostraram que os instrumentos com plano radial, maior número de espiras, menor área da secção transversal e tratamento de superfície, tendem a ter maior resistência à fadiga cíclica.

Xu *et al.* (2006), que estudaram o comportamento de instrumentos de Níquel-Titânio em testes de torção e flexão, e mostraram que as secções de tripla hélice e formas triangulares convexas apresentaram melhores distribuições de forças quando comparadas às secções transversais dos tipos Z, S ou triângulares, parecendo ser mais resistentes às falhas por torção devido às secções com maior área. Um dos motivos desse comportamento citado acima, em relação à fratura por torção, é o núcleo central do instrumento. Este núcleo depende exclusiva e diretamente da secção transversal do mesmo, pois se baseia no maior círculo inscrito na secção transversal.

Baek *et al.* (2011) reforçaram a idéia da importância desse núcleo, mostrando que as limas com maior seção, espiras menos profundas e, consequentemente, maiores núcleos centrais, apresentaram maior resistência torcional, o que também aconteceu àquelas limas com maior número de espiras.

Assim, é muito importante estabelecer um protocolo seguro para o uso de instrumentos rotatórios, reduzindo a incidência dessas separações. Uma maneira de se alcançar tal protocolo é avaliando a carga exercida nos diversos instrumentos de uma sequência, levando em consideração as secções transversais, diâmetro, conicidades e forças exercidas durante o preparo, como o torque, por exemplo. Com essas informações, seria possível calcular as tensões exercidas em cada instrumento de um determinado sistema, durante o alargamento dos condutos, através de cálculos matemáticos.

O objetivo deste estudo foi aferir matematicamente as forças e pressões exercidas nas limas de Níquel-Titânio, durante a instrumentação rotatória, em sequências disponíveis no mercado, e criar uma sequência de instrumentação segura, que permita o mínimo de incidência de fratura com o máximo de reutilização dos instrumentos, utilizando-se para isso, uma planilha de análise matemática, bem como também, comparar essa sequência, in vitro, com outros dois sistemas.

# *Capítulo 1*

## Study of NiTi Rotary Instrumentations using a New Mathematical Analysis Platform of Enlargement Rate (M.A.P.E.R).

Vivacqua-Gomes N, Souza-Filho FJ

**Abstract**

**Aim** Throught a new mathematical platform (M.A.P.E.R.), the purpose of this study was to calculate the force and shear pressure exerted at rotary instruments in 15 sequences, and design and test a new sequence with the safest values, showed by the platform.

**Methodology** Fifteen sequences were tested in this mathematical model, which simulated the enlargement rate in each half acting millimeter of each file in all sequences. The model calculated area, forces and shear pressure in critical file sections, and a new sequence was created to reach theoretically the best of these values (RS6 Sequence). This sequence was mathematically compared with the other ones, and after that, was tested at 350 molars until breakage of 8 entire file sets.

**Results** As results, the RS6 Sequence, with better area, forces and shear pressure values was designed and tested, reaching a mean of 116.1 root canal preparations until breakage.

**Conclusions** Through the analysis of the results, it was possible to conclude that the platform used was able to simulate the enlargement of each file in all of the sequences, showing that crown-down sequences submit the tips of the files to high stress levels at the enlargement and that serial sequences at the apex, like the newly created one, better distribute the torsional forces through the file flutes, permitting files to reach high numbers of reutilization with confidence.

**Keywords:** Mathematical Model, Rotary Instrumentation, File Fracture

## Introduction

Rotary endodontics showed to be a great evolution in cleaning and shaping root canals more rapidly, maintaining length with less transportation than flexible manual files (Schafer 2001). Peru *et al.* (2006) concluded that GT and ProTaper rotary systems prepared root canals faster and with less procedural errors than the manual double flare technique.

There are no relevant differences in mechanized root canal cleaning compared to manual techniques. Authors as Prati *et al.* (2004) showed no differences between manual and rotary instrumentations in debris and smear layer removal and also Jardine & Gulabivala (2000) reached similar preparations between manual and rotary instrumentations. Yet Ahlquist *et al.* (2001) showed better cleaning only in apical third using manual stainless steel files than with rotary NiTi ProFile.

However, the major problem in NiTi rotary instrumentation is the unexpected file failure compared to manual K-files (Schafer & Schlingemann 2003). According to Cheung *et al.* (2007), 14% of either manual or engine-driven discarded ProTaper instruments fractured, even when using them only in a predictable number of teeth. Such failure could endanger root canal treatment in order to be very difficult to remove some fragments (Shen *et al.* 2004).

Two failure modes are responsible for file fracture. Flexural fatigue occurs mainly when rotating in curved root canal sections and torsional fatigue occurs in every canal types, even in straight ones. Melo *et al.* (2008) studied both modes of failure and concluded that tested files cycled 700 times until its fracture, whereas twisted ones fractured with low torques values.

Whipple *et al.* (2009) showed a cyclic fatigue test with files of various shapes and diameters in severe curvatures. Rotating with a continuous axial oscillation, the files lasts from 189 (greater diameters) to 1090 (smaller diameters) cycles. Considering 10 seconds in each use, the smaller files could be used until astounding 26 times in severe curvatures.

Best *et al.* (2004) presented an important study that showed how the file torsion angle could easily break a file. A raise of a few degrees in the torsion angle could reduce drastically the file longevity. These studies suggest that torsion could be a worse mode of file breakage than fatigue. Whereas the center core could be an important feature on preventing files breakage by torsion. This core depends on the file cross section. Baek *et al.* (2011) showed that files with larger section and center cores had higher torsional stiffness, which also happened in those files with a higher number of threads.

Therefore, achieving a safety rotary protocol to avoid a high incidence of file fracture is a must. In order to achieve that protocol, it is necessary to evaluate the file load of various manufacturers' file sequences using enlargement rate patterns, calculated by a new mathematical model which is the purpose of this study.

## Materials and Methods

The current study has utilized a newly designed Mathematical Analyses Platform of Enlargement Rate (M.A.P.E.R.) with the support of the Microsoft Office Excel 2007 software (Microsoft, USA). This platform consists on a table containing columns for entering data of all the files used in endodontic instrumentation. Each column is divided in 26 rows, allowing on the insertion of the diameter of each instrument on every half millimeter (mm) of an entire sequence. First at all, a standard root canal format was inserted on the platform before start entering the instrumentation sequences data. For this study, it was select to establish root canal patency with a file tip #15 equivalent, 1 mm beyond the apex. This was standardized for all instrumentation sequences, as well as the 3 first cervical millimeters with a simulated #20 LA Axxess (Sybron Endo Kerr, Orange, USA) anti-curvature preparation. The Microsoft Excel cells were filled with the data of fifteen manufacturers file tips and tapers and their respective sequences, with the desired penetration of each instrument on each stroke or peck; plus a new group that was created (Group 1). In cases where files presented multi-taper, like ProTaper System, an extra table were used to transfer data through formulas in each cell. The first peck of all the files on every sequence was determined by that depth where the file first touched the root canal wall. Each file penetrated several pecks, advancing 0.5 mm each one. The number of pecks depended on the distance to the chosen final penetration depth of each file, with individual results to each one.

After entered a file tip, taper and penetration pecks, columns at right automatically showed, in numbers, the canal format and the area enlargement percentage in each half millimeter of root canal length, after each file peck use. The platform suggested the torque levels to be used with each file, based on enlargement rates. Then, through the introduction of the torque, platform could calculate the maximum force (in Newtons) exerted upon the root canal wall and the maximum shear pressure, in MPascal, for each millimeter instrumented by that file. When the file section did not touch the root canal wall, the results appears as a negative value. The files order, such as the penetration of each one, could be modified at any moment, updating the resulting information immediately. Figure 1 shows a partial print screen of M.A.P.E.R.

The calculations of all sequences were analyzed by M.A.P.E.R. and the critical sections of each file in every individual peck were identified. That critical cross section was selected according to the largest one touching the dentin, then, the platform selects the half millimeter immediately larger. That millimeter had to rotate without any root canal wall touch, presenting itself as the most probable section to suffer torsion. So, it was calculated the area of this cross section ($mm^2$), the force exerted by dentin (in Newtons), and both the torsional and the plain shear pressure (MPascal) in that cross section. The three last ones based on the torque level selected to each file. In plain shear, the calculations were made considering a lateral shear movement between two cross section plains in the critical section. Both calculations considered the cross section shape area. That area was previously achieved by Scanning Electron Microscope (SEM) images taken from each file type used in this study (JEOL JSM-5600LV, JEOL Ltd., Tokyo, Japan).

In each one of these categories, the sequences were ordered starting from the best results to the poor ones. The area started with the largest and both force and pressures started with the smallest. The sequences tested were:

Group 1: Author's newly designed "RS6" sequence

Group 2: Hero (MicroMega, Thonex, Swiss)

Crown Down – 25/.12, 25/.06, 25/.04, 25/.02, 30/.04, 30/.02

Group 3: K3 VTVT (Sybron Endo Kerr, Orange, USA)

Crown Down – 25/.10, 25/.08, 35/.06, 30/.04, 25/.06, 20/.04

Group 4: K3 G – Pack (Sybron Endo Kerr, Orange, USA)

Crown Down – 25/.12, 25/.10, 25/.08, 25/.06, 25/.04

Group 5: K3 Procedure Pack (Sybron Endo Kerr, Orange, USA)

Crown Down – 25/.10, 25/.08, 40/.06, 35/.06, 30/.06, 25/.06

Group 6: ProFile (Maillefer Dentsply, Ballaigues, Switzerland)

Crown Down – 50/.07, 40/.06, 35/.06, 30/.06, 30/.04, 25/.04

Group 7: GT (Maillefer Dentsply, Ballaigues, Switzerland)

Crown Down – 30/.08, 30/.06, 30/.04, 20/.08, 20/.06

Group 8: Quantec Modified Sequence (Sybron Endo Kerr, Orange, USA)

Crown Down – 25/.06, 25/.12, 25/.10, 25/.08, 25/.06, 25/.05, 25/.04

Group 9: Race (FKG Dentaire, La Chaux-de-Fonds, France)

Crown Down – 40/.10, 35/.08, 25/.06, 25/.04

Group 10: NRT (Mani Inc., Japan)

Crown Down – 35/.12, 35/.10, 30/.06, 30/.04, 25/.06, 25/.04

Group 11: Liberator (Miltex Inc., York, USA)

Crown Down – 94/.08, 70/.08, 60/.06, 50 e 40/.04, 35, 30 e 25/.02

Group 12: BioRace (FKG Dentaire, La Chaux-de-Fonds, France)

Two thirds – 25/.08

Apex – 15/.05, 25/.04, 25/.06

Group 13: MTwo (VDW, Munchen, Germany)

Apex – 10/.04, 15/.05, 20/.06, 25/.06

Group 14: ProTaper (Maillefer Dentsply, Ballaigues, Switzerland)

Two thirds – SX

Apex – S1, S2, F1, F2

Group 15: Prodesign Easy Endo (Miltex Inc., York, USA)

Half length - 35/.10

Apex - 20/.03, 15/.05, 22/.04, 25/.04, 20/.06, 20/.07

Group 16: Free Tip (Injecta, São Paulo, Brazil)

Two thirds – 25/.06, 25/.08, 25/.10

Apex – 15/.04, 15/.06, 20/.02, 20/.04, 20/.06, 25/.04, 25/.06

After that, we adjusted the Group 1 sequence, until it reached the best area, force and shear pressure values. Such results could only be reached with K3 Endo files (Sybron Kerr, Orange, USA), because of its cross section. So, the assembled **RS6** (**R**otary with **S**afety using **6** Files) sequence was the following:

Two thirds root canal length - 30/.06, 25/.10

Apex – 15/.04, 15/.06, 20/.06, 25/.06

This theoretical sequence was then tested on extracted teeth (FOP-UNICAMP Reasearch Ethics Committee number 189/2009). Three hundred and fifty mandibular and maxillary molars were radiographed and had their curvatures measured (Schneider 1971). Only root canals until 35 degrees of curvature were used, and were accessed with #1016 and #3082 diamond burs (Jet Burs, Sybron Beavers Dental, Morrisburg, Canada).

Apical foramens larger than #25 K-file at the apex were discarded. Then, #15 K-files (Maillefer Dentsply, Ballaigues, Switzerland) were used to establish patency until its tips were visible outside the apex, which was considered the working length. In cases where glidepath with #15 file was unable to be established, files #8, # 10 and then #15 were used. LA Axxess burs #20 (Sybron Endo Kerr, Orange, USA) were used 3 mm deep into the cervical portion at 15000 rpm and anti-curvature motion.

To avoid root canal curvature differences during teeth sequence instrumentation ordering, 35 blocks of 10 teeth each (totalizing 350 teeth) were divided according to the root canal curvatures (20 degrees average, ranging of 5 to 35 degrees) without statistical differences between the blocks ($p>0,05$).

Using an Endomate DT electric motor handpiece (NSK-Inc, Tochigi, Japan) each one of the 35 blocks (n=10) was instrumented with the newly designed sequence named RS6, using six K3 instruments (Sybron Endo Kerr, Orange, USA), until all 8 file sets failure. When all teeth of a block were prepared, the next block of teeth was started. Fractured instruments were replaced to continue the preparation. The numbers of root canals prepared were noted for each fractured file. Ten taper files were used with 350 RPM and 1.6 to 2 N.cm torque. All other files were used with 250 rpm and torque varying from 0.8 to 1.4 N.cm (some adjustments were made in M.A.P.E.R. suggested torque, which are calculated based on enlargement rate and functional file area). Irrigation was performed with 5 mL of saline solution in a 20 mL syringe and 20 x 0.55 needles (Benton-Dickinson, New Jersey, USA) followed by 0.5 mL of 2% chlorhexidine gel (Essencial Farma, Itapetininga, Brazil) in a 3 mL syringe each 2 files.

All instruments were taken to Scanning Electron Microscope for the analysis of the flutes and the fracture types (Figure 2).

Kruskall Wallis (Student-Newman-Kauls method) statistical test was applied with 5% significance, between the files of RS6 sequence, considering mean number of uses per file. A simple linear regression test was also applied to detect the influence of force, area and pressure on the files usage.

## Results

The overview of all sixteen sequences can be seen at the Tables 1 and 2. The results show the average of area, force, plain and shear pressures considering all pecks of the entire sequence (General) and the average of only the first peck of each instrument in the entire sequence ($1^{o}$ Stroke). The first peck was also analyzed because they always presented the worst results in area, forces and pressures.

The sequence designed by the author reach the first position in all analyses, as expected. In the force and area analyses, some other systems showed very close results, but in the most important analyses (because were calculated based on both area and force), the pressure ones (Table 2), K3 RS6 sequence presented superior results when compared to the others. In torsional shear pressure, M.A.P.E.R. calculates the highest pressure suffered by the critical section in rotation, according to the torque selected to that file.

Table 3 shows the number of uses of all 47 broken instruments (one 15/.04 file did not broke) of the Group 1 with their fragment size, fractured section diameter ($10^{-2}$ mm) and the number of root canals prepared by each file size. The mean root canal preparation until failure, considering the entire sequence, reaches 116.1 canals, with minimum of 38 and maximum of 185 uses. Bold numbers show the files that failure exactly inside M.A.P.E.R.'s prediction. The other ones separate very near to the prediction or appear to have their critical millimeters too large to fracture in normal conditions. Therefore, they separate at slightly smaller diameters.

Considering all eight 25/.10 used files, only one of them fractured above 0.65 mm diameter (0.70 mm), when the critical one, pointed by the platform, starts at 0.85 mm. About 20/.06 and 25/.06 files, only one file (25/.06) fractured above 0.60 mm (0.61 mm), when platform's critical section starts at 0.65 and 0.76 mm, respectively to files 20 and

25/.06 (Table 3). It shows that it is very difficult to fracture a file above a 0.60 mm diameter.

Broken fragments measured 2 to 7 mm long, and all the files reached high number of prepared root canals. Each root canal was counted as one use. Files 30/.06 prepared a mean of 150.4 uses, the highest valor due to its large diameter and its use to prepare just the straight thirds of root canals, which results in both low torsional and flexural pressure. These files did not presented statistical differences both to file 25/.10 (that showed a value of 148.8 uses until breakage) due also for the same motives of 30/.06 files, and also to 20/.06 (124.4 mean uses) that presented incredibly all 8 files fractured after 100 root canals. Both files 15/.06 (96.8 mean uses), that presented 6 of 8 files with fractures higher than 90 canals, and 25/.06 (97.5 mean uses), that showed 7 of 8 files with failure above 90 root canals, did not present statistical differences when compared to 20/.06 files, but with differences to 30/.06, 25/.10 and 15/.04.

Instruments 15/.04 were the worst of the sequence, with 78.1 preparations, because of small both tip diameter and taper, but without differences only to 15/.06 and 25/.06 ($p<0.05$). How these 15/.04 files were not used in all canals (just in the constrict ones), they were counted only in those occasions. It happened in approximately two thirds of total root canals, theoretically reaching 117.15 uses if they were counted for all canals.

Some Regression tests were also applied to correlate force, area and pressures with the number of uses until breakage. Only area did not show a positive correlation. Mean force in critical section presented itself 27.1% responsible for file lifetime until fracture ($p<0.001$). Plain shear pressure is responsible for 13.46% ($p<0.01$), followed by torsional shear pressure, with 13.43% ($p<0.01$).

## Discussion

As an important role in Endodontic treatment, several studies compared file separation between some of the available systems. Troian *et al.* (2006) prepared 100 simulated canals using 10 sets of RaCe and K3 instruments, with all 25/.04 files of both systems analyzed by SEM. Each set of instruments prepared only 5 root canals in resin blocks and none of the ten K3 instruments distorted or fractured, remaining virtually the same. Otherwise, 6 out of the 10 RaCe instruments separated, with a progressive increase in unwinding and surface wear occurrence with each consecutive use.

Some authors already shown that RaCe files presented itself as one of the most flexible systems, as shown by Tripi *et al.* (2006), part of it because of its surface treatment. And we also knew that K3 file had shown itself less flexible than all other systems (Melo *et al.* 2008, Barbosa *et al.* 2008, Gambarini *et al.* 2008, Schafer *et al.* 2003), part of it because its larger central core and radial lands (Gambarini *et al.* 2008, Melo *et al.* 2008). Schafer *et al.* (2003) showed that K3 files had more cross section area than FlexMaster, Hero, ProFile and RaCe, only an exception made for Hero 0.06 files. But K3 files still presented more bending resistance than all other systems (a characteristic presented by the most rigid files), even when compared with Hero 0.06 files. However, it is an interesting result that the less flexible file resisted more on curvatures than the most flexible one, as showed by Troian *et al.* (2006).

Shen *et al.* (2006) studied the fracture incidence in clinical practice with ProFile and ProTaper instruments. Over 17 months, 7% of ProFile instruments separated, with 5% of unwinding, and 14% of ProTaper files fractures, with 0.3% of unwinding. Two thirds of ProFile that distorted or fractured were of 0.04 taper and ProTaper S1 files were also the most frequently discarded. Grande *et al.* (2006) proved that S1 files are one of the most flexible files in ProTaper sequence. Nevertheless, if they are both the most flexible files in their sequences, why did fractures by flexural fatigue occurred in 8 of 12 separated

ProFiles and in 43 of 45 fractured ProTapers, as reported by the authors, considering that the flexible ones resist quite better to curvatures than the rigid ones?

Grande *et al.* (2006) also studied MTwo files, and they have shown themselves quite resistant to curvatures, when compared with ProTaper in 60 degrees and 2 or 5 mm radii curvatures. But the same MTwo demonstrated almost the worst results in the study carried out by Tripi *et al.* (2006), in just 45 degrees and 5 mm radii curvatures, even when compared with less flexible systems.

The figure 2 shows SEM photographs of the broken files. Only 15/.04 and 15/.06 files (A, B and C) fractured exclusively by torsion. We can identify a plain separated section with or without flutes twisting. It happens with small diameter files, which have not torsion resistance. This is a premature failure. The other files (D to H) fractured probably by flexural fatigue or mixed modes. Avoiding premature torsion, the NiTi alloy was taken to its edge, and lasted very long.

Bahia *et al.* (2006) tested ProFile instruments and concluded that previously cycled instruments in curvatures caused significant reduction on torsional test results, when compared with the new files, even if the flexural and torsional cycles were applied separately. And Barbosa *et al.* (2008) tested K3 files to flexural fatigue with or without previous torsion tests. They concluded that the higher is the angular deformation in previous torsion tests, the lower is the resistance the files presented to cyclic flexural fatigue, also applied separately. In that manner, we can conclude that if both forces occur at the same time during root canal preparations, we must realize which of these stresses are more important to file fracture in each case, and choose which file or sequence will be used in order to reduce them, as shown in this study.

Overall, the prediction of the root canal anatomy is not possible, so a few files in this study (4 files) failure too soon when compared to the others of the same number. Probably, some complications in root canals anatomy, which were not predicted by radiographs, caused extensive flexural fatigue in those files, causing them to earlier failure. A 25/.10 (58 uses) were inadvertently used after the curved portion, and being a low flexible file, the flexural fatigue broke it easily (Figure 2H). Some 15/.04 files break much sooner, probably also because of the root canal anatomy. They were always the first rotary file to reach the foramen. Figures 2A and 2C show these files with a failure by torsion, with and without distortion, respectively. A 15/.06 (38 uses) went through a severe apical curvature at foramen level, breaking prematurely by combined modes (flexural and torsional fatigue), as seen on Figure 2D. Another 15/.06 file fractured exclusively by torsion, with distorted flutes, as seen on Figure 2B. A 25/.06 file (46 uses), separated without any apparent cause, but analyzing SEM image, we can assume that it probably separated by fatigue (Figure 2F).

According to Xu *et al.* (2006), files with radial lands, more cross section area, more inner core, more peripheral surface ground and less depth of the flutes, are more torque resistant. So, triple helix files with radial land are the best torque resistant files, in comparison with triangle, S, Z, rectangle, and those files without radial lands. The K3 files have exactly these characteristics, and were chosen first because of its triple helix cross section, large center core, radial lands, and greater number of spirals and secondly because of its larger variety of tip and taper numbers. This last one gave us freedom to assemble any kind of sequence. Also on the other hand, low diameter instruments are the worst in torsion resistance, as showed in this study by premature failure of 15/.04 files.

As the cyclic fatigue is worse in curved canals (Troian *et al.* 2006), the torsional failure is much more important to understand, because it happens in all cases, without exception (Best *et al.* 2004, Bahia *et al.* 2006, Barbosa *et al.* 2008). Unfortunately, almost all studies are focused on fatigue. As the great majority of the teeth are low curved ones, the instrument and the sequence have a great role on enlargement distribution, decreasing torsion. M.A.P.E.R. had shown itself an important tool to better understand the files load per millimeter in any instrumentation sequence, but without considering curvatures. The total file load itself did not mean much, except for the need of higher torques and apical forces (Peters *et al.*, 2003). When it occurs, pre-flaring with cervical files must be repeated. However, larger critical sections appeared to difficult penetration in root canals. After all, the importance must be focused on the load distribution among file first millimeters, so that we can actually reduce torsional stress, as seen in this study. The chosen sequence has to be balanced to decrease greater loads on file tips, distributing them through five or more tip millimeters. Through this, as the critical section (the first coronal inactive cross section) will be larger, it will be more torsional resistant too (Xu *et al.* 2006). But

According to M.A.P.E.R., the crown down sequences appear to have greater loadings on file tips, and serial to the apex sequences, with pre-flaring, showed themselves better on load distribution, allowing files to last much more as shown in this study. When we did not applied pre-flaring, the torque needed to rotate the files was too high, raising forces and pressures. As shown on Tables 1 and 2, any modification in K3 using sequence (VTVT, G-Pack and P-Pack), resulted in very different values of Force, Area and Pressures, and could compromise file longevity.

Apparently, the larger the taper, the larger is the last active file section (more torsional resistant), but also lesser resistant to fatigue cycle (Low *et al.* 2006), being indicated only to straight or low curvature root canals (until 35 degrees) as used in this study. Both 30/.06 and 25/.10 cervical files last too much when compared to the others (Table 3), because they did not suffer flexural fatigue in the straight root canal portion. That manner we could control, through M.A.P.E.R., the critical sections to avoid torsion, permitting files to reach their alloy limits. The files which were used in the apical portion, despite of low curvatures, suffered both torsion and flexural fatigue, separating earlier, even with M.A.P.E.R.'s critical section control.

The RS6 sequence showed the best results at all in this mathematical platform, and also presented in vitro a mean 116.1 canals prepared until fracture, with only 6 out of 47 instruments fractured below 60 canals with just 3 of them, fractured below 56 uses, an astounding result. Those were very large numbers in comparison to other studies, like Shen *et al.* (2004), for example. However, as almost all the files are of 0.06 taper, they have low flexibility (Low *et al.* 2006), and must be avoided in severely curved root canal preparations. Nevertheless, the RS6 sequence proved itself to be very safe, considering the preparations until 35 degrees root canal curvatures.

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Figure 1 – Mathematical Analysis Platform of Enlargement Rate (M.A.P.E.R) partial print screen.

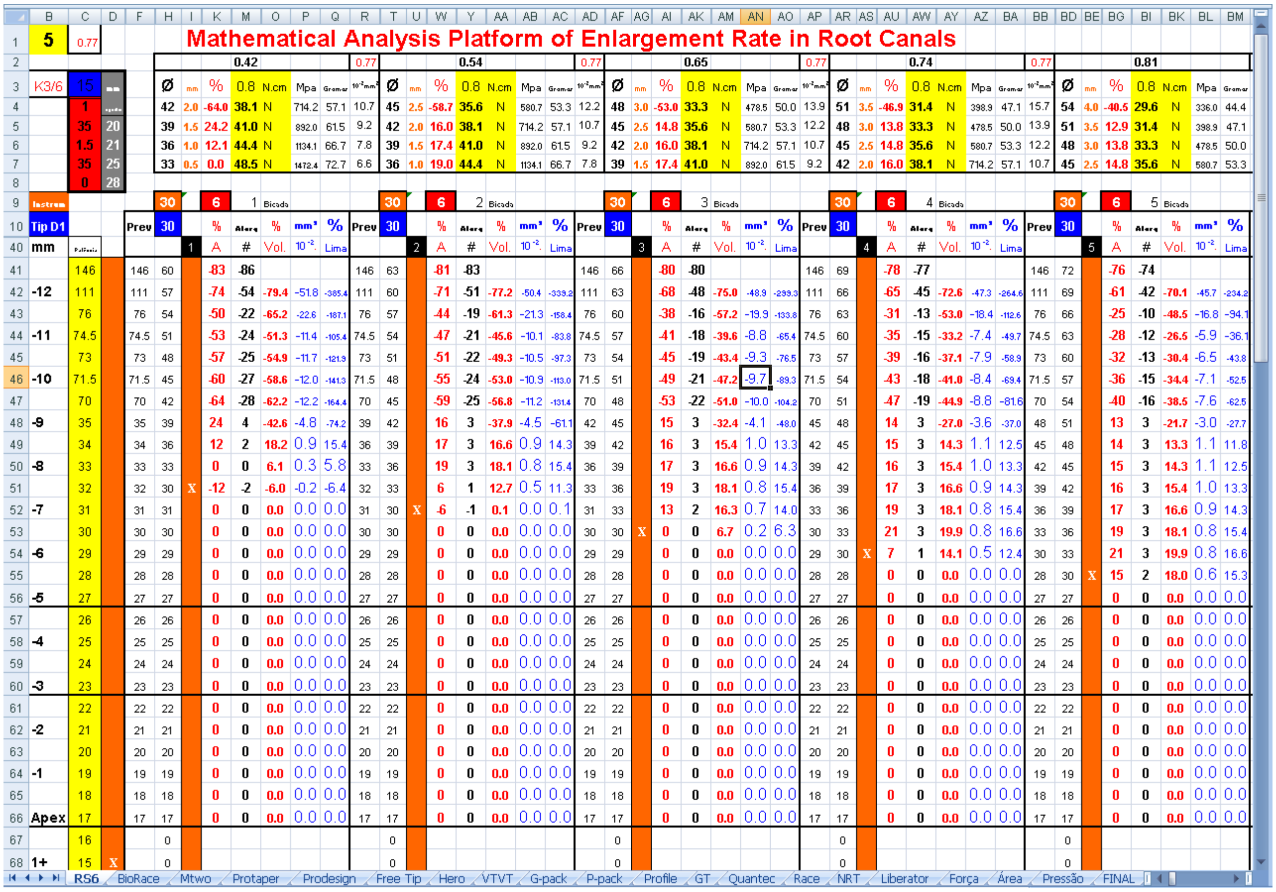


Table 1 – Values of force (in Newtons) and Area (in $10^{-2}$ $mm^2$), of the critical section, of all pecks (General) in the entire sequence and only of the first peck (stroke) of each file of the entire sequence.

| General | Mean Force (N) | 1° Stroke | Mean Force (N) | General | Mean Area ($10^{-2}$ $mm^2$) | 1° Stroke | Mean Area ($10^{-2}$ $mm^2$) |
|---|---|---|---|---|---|---|---|
| RS6 | 35.00 | RS6 | 39.22 | RS6 | 22.49 | RS6 | 19.51 |
| Free Tip | 37.06 | Liberator | 39.24 | Prodesign | 22.44 | Mtwo | 17.10 |
| Quantec | 37.21 | Free Tip | 41.00 | Hero | 22.39 | Prodesign | 14.03 |
| Liberator | 37.59 | Mtwo | 43.50 | ProTaper | 22.21 | GT | 12.93 |
| ProFile | 39.06 | Quantec | 43.66 | G-Pack | 19.77 | VTVT | 12.64 |
| VTVT | 39.34 | ProFile | 44.52 | Mtwo | 19.63 | ProTaper | 11.99 |
| Mtwo | 39.93 | Prodesign | 45.19 | P-Pack | 19.16 | Free Tip | 11.80 |
| GT | 40.05 | GT | 45.85 | GT | 19.04 | Liberator | 10.75 |
| Prodesign | 40.17 | VTVT | 47.62 | VTVT | 18.22 | Quantec | 10.39 |
| Hero | 40.71 | Hero | 50.67 | NRT | 16.13 | Hero | 08.44 |
| G-Pack | 40.86 | G-Pack | 52.56 | Free Tip | 15.51 | G-Pack | 08.26 |
| NRT | 42.91 | ProTaper | 55.32 | Liberator | 15.14 | P-Pack | 08.13 |
| ProTaper | 43.51 | BioRace | 56.09 | Quantec | 14.34 | BioRace | 07.36 |
| BioRace | 43.80 | NRT | 56.92 | BioRace | 13.51 | NRT | 06.32 |
| Race | 47.09 | P-Pack | 60.22 | Race | 12.93 | ProFile | 05.88 |
| P-Pack | 47.16 | Race | 62.54 | ProFile | 12.85 | Race | 04.43 |

Table 2 - Values of Torsion Shear Pressure (MPa) and Plain Shear Pressure (MPa), of the critical section, of all pecks (General) in the entire sequence and only of the first peck (1º Stroke) of each file of the entire sequence.

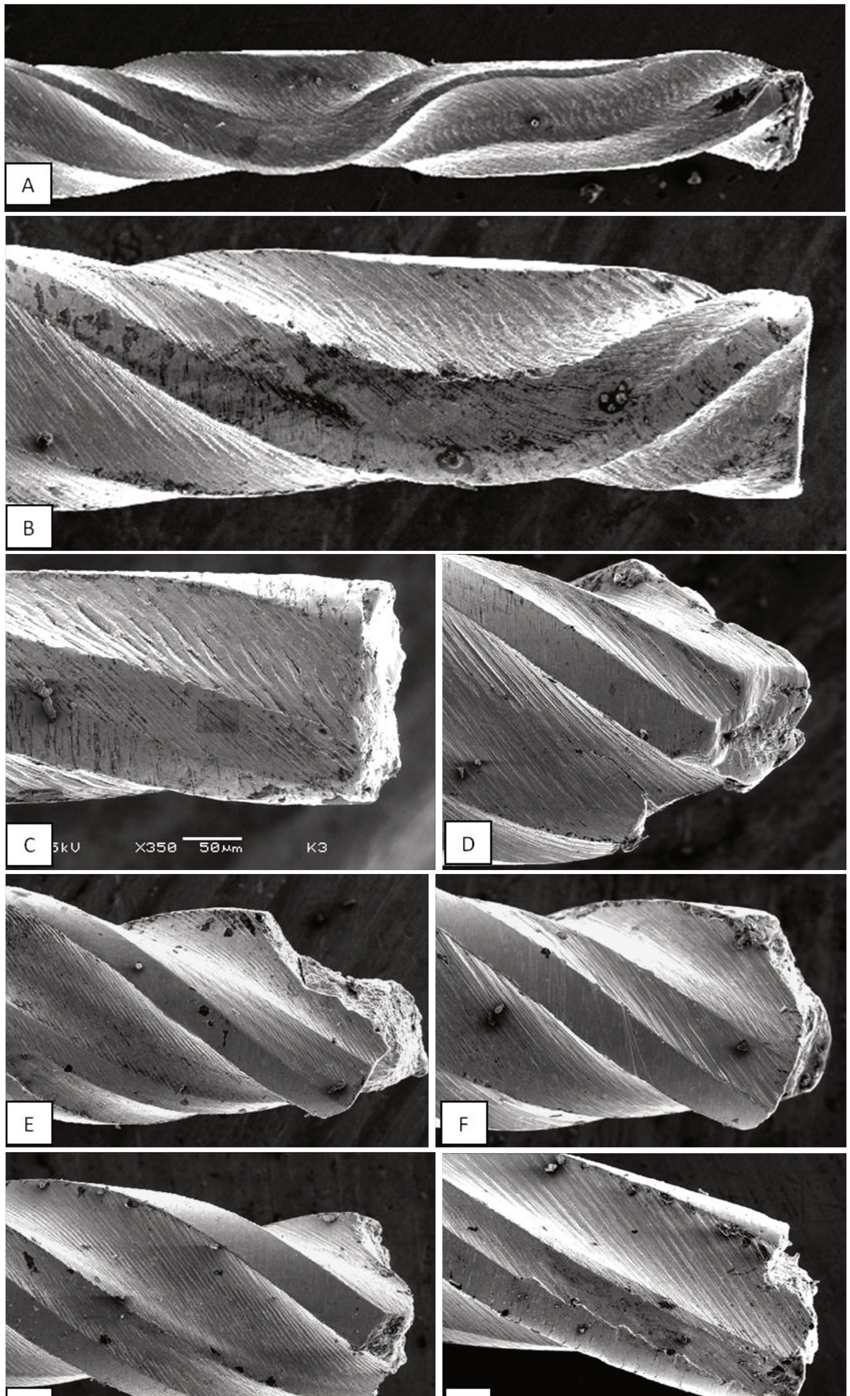
| General | Torsion Shear (Mpa) | 1º Stroke | Torsion Shear (Mpa) | General | Plain Shear (Mpa) | 1º Stroke | Plain Shear (Mpa) |
|---|---|---|---|---|---|---|---|
| RS6 | 461.90 | RS6 | 628.59 | RS6 | 231.0 | RS6 | 314.3 |
| Mtwo | 603.33 | Mtwo | 741.26 | Mtwo | 301.7 | Mtwo | 370.6 |
| ProTaper | 616.82 | Prodesign | 983.25 | Protaper | 308.4 | Prodesign | 491.6 |
| GT | 662.82 | GT | 1041.05 | GT | 331.4 | GT | 520.5 |
| G-pack | 689.89 | ProTaper | 1141.82 | G-pack' | 344.9 | Protaper | 570.9 |
| Prodesign | 695.08 | G-pack | 1296.16 | Prodesign | 347.5 | G-pack' | 648.1 |
| Hero | 790.97 | Quantec | 1304.78 | Hero | 395.5 | Quantec | 652.4 |
| VTVT | 825.91 | Liberator | 1314.21 | VTVT | 413.0 | Liberator | 657.1 |
| P-pack | 853.33 | VTVT | 1350.29 | P-pack' | 426.7 | VTVT | 675.1 |
| Quantec | 859.02 | Hero | 1459.07 | Quantec | 429.5 | Hero | 729.5 |
| Liberator | 1016.58 | Free Tip | 1487.77 | Liberator | 508.3 | Free Tip' | 743.9 |
| Free Tip | 1017.57 | P-pack | 1649.12 | Free Tip' | 508.8 | P-pack' | 824.6 |
| Profile | 1056.43 | Profile | 1825.98 | Profile | 528.2 | Profile | 913.0 |
| BioRace | 1151.58 | BioRace | 2355.41 | BioRace | 575.8 | BioRace | 1177.7 |
| NRT | 1235.98 | NRT | 2700.39 | NRT | 618.0 | NRT | 1350.2 |
| Race | 1462.03 | Race | 3063.96 | Race | 731.0 | Race | 1532.0 |

Table 3 – Number of utilization (root canals), fragment size (mm) and fractured section diameter ($10^{-2}$ mm) of all files used in the study, per file number, of group 1 (K3 RS6 sequence).

| Files | Root canals until failure (8 File Kits) | | | | | | | | Mean (sd) |
|---|---|---|---|---|---|---|---|---|---|
| 30/.06 | **127** | **158** | 167 | 175 | **180** | 121 | **102** | 173 | 150.4 (±29.47) a |
| Fragm. | **3** | **3** | 7 | 6.5 | **4** | 5 | **4** | 5 | 4.7 (±1.49) |
| Section | **48** | **48** | 72 | 69 | **54** | 60 | **54** | 60 | 58.1 (±8.82) |
| 25/.10 | 58 | 145 | 174 | 171 | 152 | 166 | 147 | 177 | 148.84 (±38.71) a |
| Fragm. | 3 | 4 | 4 | 4 | 3.5 | 4 | 3 | 4.5 | 3.8 (±0.53) |
| Section | 55 | 65 | 65 | 65 | 60 | 65 | 55 | 70 | 62.5 (±5.35) |
| 15/.04 | 126 | 69 | 57 | **101** | 38 | 56 | **100** | | 78.14 (±31.42) c |
| Fragm. | 2 | 7 | 6.5 | **4** | 3 | 3 | **4** | | 4.2 (±1.87) |
| Section | 23 | 43 | 41 | **31** | 27 | 27 | **31** | | 31.9 (±7.47) |
| 15/.06 | 38 | **74** | 92 | 98 | **139** | **113** | **114** | **106** | 96.84 (±30.30) bc |
| Fragm. | 2 | **5** | 3.5 | 4 | **7** | **5.5** | **6** | **5** | 4.8 (±1.56) |
| Section | 27 | **45** | 36 | 39 | **57** | **48** | **51** | **45** | 43.5 (±9.35) |
| 20/.06 | 116 | 110 | 126 | 129 | 109 | 185 | 103 | 117 | 124.44 (±25.98) ab |
| Fragm. | 6 | 4 | 2.5 | 3 | 5.5 | 6.5 | 4 | 6 | 4.7 (±1.51) |
| Section | 56 | 44 | 35 | 38 | 53 | 59 | 44 | 56 | 48.1 (±9.06) |
| 25/.06 | 46 | 119 | 105 | 101 | 104 | 117 | 92 | 96 | 97.54 (±22.8) bc |
| Fragm. | 3 | 5 | 5.5 | 6 | 5 | 5 | 5 | 4 | 4.8 (±0.92) |
| Section | 43 | 55 | 58 | 61 | 55 | 55 | 55 | 49 | 53.9 (±5.54) |

Different letters indicate statistical significant differences according to Kruskall Wallis test with Student-Newman-Kauls method ($p<0.05$).

Figure 2 – Separated files from K3 RS6 Sequence.




A –15/.04, B – 15/.06, C – 15/.04 separated by premature torsion. D – 15/.06; E– 20/.06, F – 25/.06, G – 30/.06, H – 25/.10 separated by alloy fatigue (mixed modes).

# *Capítulo 2*

## Evaluation of File Longevity on Comparison of Three NiTi Rotary Systems: K3 RS6, ProDesign and ProTaper.

Vivacqua-Gomes N, Souza-Filho FJ

**Abstract**

**Aim** To compare the file breakage of 3 rotary instrumentation sequences and correlate them with the area, forces and pressure exerted on file flutes calculated by a mathematical platform.

**Methodology** In this study, a new mathematical platform named Root Canal M.A.P.E.R. (Root Canal Mathematical Analysis Platform of Enlargement Rate) was used to calculate the root canal enlargement rate, area, forces and shear pressure in critical file sections of the following sequences: ProDesign (Easy Endo), ProTaper (Maillefer), and a newly designed sequence using K3 Sybron Endo files (RS6 Sequence). In conjunction with the mathematical platform, 200 maxillary and mandibular molar teeth with slightly curved roots were prepared and instrumented with these three sequences in duplicate until all instrument failure. It was analyzed the number of uses and the size of the separated fragment of each instrument. This information was then compared to the platform results.

**Results** The newly designed sequence using K3 instruments showed better results in the enlargement rate and lower number of separate instruments, with 110 mean root canals prepared per sequence until failure, followed by Prodesign (78.5) and ProTaper (46.6), presenting statistical differences between each other ($p<0.05$). In most cases the separation occurs near the point of higher tension of the instruments in the root canal wall enlargement, and the platform results corroborate with the number of uses of each systems.

**Conclusions** We conclude that the Root Canal M.AP.E.R. was able to calculate enlargement rate and critical cross section area, forces and pressures in each one of the instruments of all three sequences used. The RS6 sequence appeared to be predictable in relation to fractured files and presented a better longevity when compared to the other two sequences.

**Keywords**: Rotary Instrumentation, File Longevity, File Fracture

## Introduction

Rotary instrumentation of root canals has been important in clinical endodontic, making the root canal treatment easier and faster. However, the separation of instruments caused by torsion or flexural fatigue has worried endodontists and still represents a major problem in rotary endodontics (Wei *et al.* 2007).

The cyclic fatigue resistance decreases when the instruments are used repeatedly in comparison with the new ones (Fife *et al.* 2004). Then, several models were trying to get more stiffness and flexibility for the instruments. According to Cheung & Darvell (2007), different sections do not appear to increase the resistance to cyclic fatigue of NiTi instruments at different levels of curvature, but Tripi *et al.* (2006) showed that the instruments with radial land, larger number of flutes, smaller cross-sectional area and surface treatment, seem to have more resistance to cyclic fatigue. Xu *et al.* (2006) who studied the behavior of NiTi instruments in severe torsional and bending tests, showed that the triple helix and convex forms presented a better distribution of forces, appearing to be more resistant to torsional failure.

Another important factor in the separation of instruments is the force and torque applied to rotate the files. Peters *et al.* (2003) measured the torque and force in molar root canals instrumented using ProTaper files, showing a great variety, depending on the curvature of the root canal and previous enlargement. Force was also greater in constricted root canals. Thus, a point of great importance is the sequence of files. According to the previous enlargement, the subsequent files will suffer different force distributions along its flutes, causing its distortion and even separation.

The objective of this study was to evaluate the number of uses of three rotary NiTi file sequences and correlate the fracture and fractured sections, with each file's enlargement rate, calculated by a new mathematical model named "Root Canal Mathematical Analysis Platform of Enlargement Rate" (Root Canal M.A.P.E.R.).

## Materials and Methods

The current study has utilized a newly designed mathematical platform (M.A.P.E.R.) with the support of the Microsoft Office Excel 2007 software (Microsoft, USA). This platform consists on a table containing columns for entering data of all the files used in endodontic instrumentation. Each column is divided in 26 rows, allowing on the insertion of the diameter of each instrument on every half millimeter (mm) of an entire sequence. First at all, a standard root canal format was inserted on the platform before start entering the instrumentation sequences data. For this study, it was select to establish root canal patency with a file tip #15 equivalent, 1 mm beyond the apex. This was standardized for all instrumentation sequences, as well as the 3 first cervical millimeters with a simulated #20 LA Axxess (Sybron Endo Kerr, Orange, USA) anti-curvature preparation. The Microsoft Excel cells were filled with the data of three manufacturers file tips and tapers and their respective sequences, with the desired penetration of each instrument on each stroke or peck. In cases where files presented multi-taper, like ProTaper System, an extra table were used to transfer data through formulas in each cell. The first peck of all the files on every sequence was determined by that depth where the file first touched the root canal wall. Each file penetrated several pecks, advancing 0.5 mm each one. The number of pecks depended on the distance to the chosen final penetration depth of each file, with individual results to each one.

After entered a file tip, taper and penetration pecks, columns at right automatically showed, in numbers, the canal format and the area enlargement percentage in each half millimeter of root canal length, after each file peck use. The platform suggested the torque levels to be used with each file, based on enlargement rates. Then, through the introduction of the torque, platform could calculate the maximum force (in Newtons) exerted upon the root canal wall and the maximum shear pressure, in MPascal, for each millimeter instrumented by that file. When the file section did not touch the root canal wall, the results appears as a negative value. The files order, such as the penetration of each one could be modified at any moment, updating the resulting information immediately.

The calculations of all sequences were analyzed by M.A.P.E.R. and the critical sections of each file in every individual peck were identified. That cross section was selected according to the largest one touching the dentin, then, the platform selects the half millimeter immediately larger. That millimeter had to rotate without any root canal wall touch, presenting itself as the most probable section to suffer torsion. So, it was calculated the area of this cross section ($mm^2$), the force exerted by dentin (in Newtons), and both the torsional and the plain shear pressure (MPascal) in that cross section. The three last ones based on the torque level selected to each file. In plain shear, the calculations were made considering a lateral shear movement between two cross section plains in the critical section. Both calculations considered the cross section shape area. That area was previously achieved by Scanning Electron Microscope (SEM) images taken from each file type used in this study (JEOL JSM5600LV, JEOL Ltd., Tokyo, Japan) (Figures 1 to 3).

A newly sequence was then designed according to the best distribution rates of enlargement (author's sequence) using K3 Endo files (Sybron Endo Kerr, Orange, USA). This sequence was named K3 RS6 (Rotary with Safety using 6 files) and it was compared with the ProTaper and ProDesign sequences. The sequences tested were:

Group 1: K3 RS6 (Sybron Endo Kerr, Orange USA)

30/.06, 25/.10 - Two thirds root canal length

15/.04, 15/.06, 20/.06, 25/.06 – Until the foramen

Group 2: ProTaper (Maillefer, Ballaigues Switzerland)

SX - Two thirds root canal length

S1, S2, F1, F2 - Until the foramen

Group 3: Prodesign Endo (Easy, Belo Horizonte Brazil)

35/.10 - Half root canal length

20/.03, 15/.05, 22/.04, 25/.04, 20/.06, 20/.07 - Until the foramen

After that, 200 mandibular and maxillary molars (FOP-UNICAMP Reasearch Ethics Committee number 189/2009) were radiographed and had their curvatures measured (Schneider 1971). Only root canals until 35 degrees were used, and were accessed with #1016 and #3082 diamond burs (Jet Burs, Sybron Beavers Dental, Morrisburg, Canada). Apical foramens larger than #25 K-file at the foramen were discarded.

Then, #15 K-files (Maillefer Dentsply, Ballaigues, Switzerland) were used to establish the patency until its tips were visible outside the apex, which was considered the working length. In cases where glidepath with #15 file was unable to be established, files #8, # 10 and then #15 were used. LA Axxess burs #20 (Sybron Endo Kerr, Orange, USA) were used 3 mm deep into cervical third with 15000 rpm and anti-curvature motion. To avoid root canal curvature differences during teeth sequence instrumentation ordering, 20 blocks of 10 teeth were divided according to the root canal curvatures (20 degrees average, ranging of 5 to 35 degrees) without statistical differences between the blocks ($p>0,05$).

Using an Endomate DT electric motor handpiece (NSK-Inc, Tochigi, Japan) each block (n=10) was instrumented with one of the three sequences until all instrument failure in duplicates. When all teeth of a block were prepared, the next block of teeth was started. Fractured instruments were replaced to continue the preparation. The number of root canals prepared was noted for each fractured file. Ten taper and SX files were used with 350 RPM and 1.6 to 2 N.cm torque. All other files were used with 250 rpm and torque varying from 0.8 to 1.4 N.cm (some adjustments were made in M.A.P.E.R. suggested torque, which are calculated based on enlargement rate and file area used). Irrigation was performed with 5 mL of saline solution in a 20 mL syringe and 20 x 0.55 needle (Benton-Dickinson, New Jersey, USA) followed by 0.5 mL of 2% chlorhexidine gel (Essencial Farma, Itapetininga, Brazil) in a 3 mL syringe each 2 files.

The M.A.P.E.R. results were compared with fractured sections and also correlated with the number of uses of each file of all sequences. All instruments were taken to Scanning Electron Microscope to analyze flutes and the fracture type. ANOVA and Kruskall Wallis (Student-Newman-Kauls method) statistical tests were applied with 5% significance, between groups, considering mean number of uses per file, mean force, mean section area and mean pressure (plain and torsional shear) of the critical sections in each stroke. A simple linear regression test was also applied to detect the influence of force, area and pressure on the files usage.

## Results

All the broken files in each one of the three sequences were compared to the mathematical model results. The fractured diameter, the number of uses until fracture, and the M.A.P.E.R.'s section area, the forces and the pressures in critical section per file are shown in Tables 1, 2 and 3.

In group 1 (Table 1), K3 files last 121/102 uses (30/.06), 56/100 uses (15/.04), 114/106 uses (15/.06), 103/117 (20/.06) and 92/96 uses (25/.06). Both 25/.10 orifice opener files fractured with 166 and 147 uses, but they start to lose efficiency much sooner than that. Each root canal was counted as one use. The fragments had 3 to 6 mm long, and the fractured section 0.27 to 0.65 mm diameter.

In group 2 (Table 2), ProTaper files last 44/48 uses (SX), 44/50 uses (S1), 42/48 uses (S2), 55/45 uses (F1) and 43/47 uses (F2). The fragments had 3 to 6 mm long, and the fractured section 0.325 to 0.615 mm diameter.

In group 3 (Table 3), files last 29/49/40/55 uses (20/.03), 52/73/69 uses (15/.05), 91/101 uses (22/.04), 103/99 uses (25/.04), 98/105 uses (20/.06) and 106/97 (20/.07). Orifice opener 35/.10 fractured with 89 and 80 uses. The fragments had 3 to 6.5 mm and the fracture section had 0.20 to 0.65 mm diameter.

About the mean number of uses of each file, K3 RS6 (110 mean uses per file), ProTaper (46.6) and ProDesign groups (78.5) presented statistical significant differences between all of them ($p<0.05$).

The mean force, area and pressure of the critical section did not presented any statistical differences between the groups ($p>0.05$), despite of the great differences in numerical values (Table 4). The same occurred when comparing only the first strokes of each file ($p>0.05$) (Table 5).

Figures 1, 2 and 3 shows files after use. K3 files of 15 to 30/.06 presented a few striations on radial land and flexural fatigue or combined modes failure. The 25/.10 K3 orifice opener did not present striations in radial land or in flutes and also failed by flexural fatigue or combined modes (Figure 1c).

ProTaper S1 and F3 presented too much cracks and striations on cutting edges and fracture by flexural fatigue or combined modes failure. The Sx, S2, F1 and F2 presented a few cracks and striations on cutting edges and fracture also by flexural fatigue or combined modes (Figure 2).

ProDesign files presented too much micro cracks in the flutes and in the cutting edges. The instruments # 2 to # 6 and orifice openers fractured by flexural fatigue or combined modes. The # 1 files (20/.03) were the only ones in the entire study that fractured by torsion, analyzed by transversal fractography of the sectioned part and it was the instrument that fractured first at all, considering all sequences. This fact proves how torsion failure is a more important mode than fatigue failure in root canals without severe curvatures (Figure 3a).

The results of the regression test showed that on ProTaper group, neither of the values (force, area and pressure) influenced the number of uses of each file ($p>0.05$). On RS6 and ProDesign groups, only area and both pressure analyses influenced the number of uses ($p<0.05$). On RS6 group, 11.62% ($p<0.05$) of the number of uses' value was influenced by area, 25.16% ($p=0.05$) by plain shear pressure and 25.18% ($p=0.05$) by torsional shear pressure. On ProDesign group, 24.87% ($p<0.05$) of the number of uses' value was influenced by the area, 55.36% ($p<0.05$) by plain shear pressure and 55.40% ($p<0.001$) by torsional shear pressure.

## Discussion

As a major problem for rotary endodontics, instrument failure appears to be of great significance on the choice for its practice. Wei *et al.* (2007) studied modes of fracture in ProTaper after 30 uses under stereomicroscope and SEM. Three modes appear to exist when a fracture occurs: flexural fatigue (dimples, fatigue striations, and crack initiation), torsional failure (circular abrasion marks) and combined modes. Respectively, 86% of the files presented flexural fatigue, 8% torsional failure and 4% of combined modes.

Fife *et al.* (2004) presented that multiple uses of ProTaper files decreases its resistance to cyclical fatigue. After using them in 2 or 4 molars with 3 or four root canals each, almost all instruments showed a decrease in the number of rotations until fracture, compared to new files. S1 files were not affected by clinical use, maybe because they did not suffer apical forces in root canals previously enlarged by a # 20 file.

M.A.P.E.R. showed that K3 RS6 files 15/.04 and 15/.06 worked almost all time without any circumferential touch at its first millimeters, lasting too long despite of their small tip, according Fife *et al.* (2004). Once formatted with a taper 0.06 file, all posterior taper 0.06 used files will touch several millimeters at the same time, fitting the tip together with the body and distributing forces along these millimeters.

Cheung *et al.* (2005) evaluated separation modes of discarded ProTaper S1 files. Twenty three percent of the files were fractured, 66.6 % because cyclic fatigue and 33.3% by torsion. These failures occur earlier in harder curvatures (Cheung & Darvell 2007) as showed by Tripi *et al.* (2006) that studied cyclic fatigue resistance of NiTi files in a 45 degrees and 5 mm radius curvature cylinder. At 300 rpm, 25/.06 Profile, Race, K3, Hero, MTwo and Race without surface treatment fractured after 50.4, 44.9, 43.7, 20.4, 21.8, 19.35 mean seconds respectively.

Comparing each file fracture diameter with its critical diameter calculated by M.A.P.E.R., we found several similarities, as seen on Tables 1, 2 and 3 (bold numbers). Some files did not present these similarities, probably because their critical diameters are large enough to resist torsion of the used torque (0.63, 0.65, 0.745, 0.76, 0.85 and 0.865 mm). In doing so, these 12 files (6 in duplicate) presented fractures on sections near the critical ones, but on the immediate thinner part (0.44 to 0.62 mm sections). If these 12 files had fractured 1 mm beyond, 10 of them will bypass 0.60 mm sections. Of the 39 files used in this experiment, only 7 fractured beyond diameter 0.60 mm. Two of them with 0.615 mm sections (2 ProTaper F2 files), other two with 0.62 mm sections (2 Prodesign 20/.07 files) and 3 with 0.65 mm sections (1 K3 25/.10 and 2 Prodesign 35/.10 files). Only 17.9 % of the total number of used files.

Tripi *et al.* (2006) said that probably, files with radial lands and more spiral flutes (as Profile and K3) appeared to have more cyclic fatigue resistance, as in the present study, where K3 sequence lasts almost two times more uses than ProTaper files, probably because radial land better distribute flexural forces through peripheral area, instead of concentrating them in the cutting edges, which cannot be seen by Bergmans *et al.* (2003). Fatigue resistance was also higher on files with surface treatment (Race) and less cross sectional area. But according to the studies of Barbosa *et al.* (2008), Boessler *et al.* (2009), Cheung *et al.* (2007) and Bui *et al.* (2008), only files without radial lands are affected by eletropolishing. K3 and Profile, for example, did not show any improvements. It happens probably because the improvement in the surface of radial lands did not make any difference on file behavior as well as on cutting edges of non-radial land files. A polished cutting edge improves cutting and resistance to fracture, which does not happen in radial lands. It could be seen in Figure 1, whereas the radial land already presented a polished surface, in comparison with the flutes.

Wolcott *et al.* (2006) tracked ProTaper failure incidence in 4652 root canal treatments, resulting in 2.4% overall breakage. Apparently, as larger the file tip, shorter was the fragment length, what was observed in the present study too. All Shaping instruments fractured fragments measure near 5 mm, and finishing instruments between 3 to 4 mm. The authors also noted that the thinner files presented plastic deformation, a characteristic of low torsion resistant files.

Peters *et al.* (2003) showed a great variation in apical force and torque (directly proportional) during instrumentation. High torque levels were measured (5.4 N.cm), causing files to separate. For that reason, it is necessary to use a torque controlled by an electric engine, to stop and reversing rotation when excessive force was applied. More secure electric motors present full automatic auto reverse, starting rotation again after the applied force decreases. This is a very helpful characteristic of some electric engines as the one used in this study. It allows the operator to select very low torque values, increasing then the number of reverse rotation times, without wasting time due to its automatic restart rotation after auto reverse. An interesting fact is that increasing rotation will decrease torque necessary to cut dentin (Bardslay *et al.* 2011), but also it will decrease the number of rotations in curvatures until breakage (Lopes *et al.* 2009). Therefore, it could result in earlier failure.

In Easy Endo group, 15/.05 files last just 52, 69 and 73 uses, probably because it could need lower torque than the 0.8 N.cm used in this experiment, overloading it. File 20/.03 failure earlier, when compared to all other instruments to all groups, in 0.32 and 0.35 mm sections, due to its thin tip and taper, giving it low torsional resistance, which occurs in the forth to fifth millimeter of the file tip. This file probably also requires a lower torque because it was the only file that fractured exclusively by torsional failure, according to the Scanning Electron Microscope images shown in Figures 1, 2 and 3. Files 22/.04 and 25/.04 had the least percentile load. Files 20/.06 and .07 had their tip free of touching dentin until 2 to 3 mm, making their first acting mm (3 to 4 mm short of the tip) to have near 0.40 mm diameter, reducing torsion. Orifice opener 35/.10 fractured earlier when compared to the other files, probably because its low flexibility and greater load, since previous enlargement, as in group 1, does not exist.

The file flutes and cutting edges always presented some sort of crack initiations or deformations after some uses, depending of the file cross section type. Cheung & Darvell (2007) showed crack initiation on radial lands or cutting edges of all ProFile instruments. Hero and FlexMaster files presented it on cutting edges and K3 files on cutting edges and along the flutes. Files with radial lands as Profile, K3 and Hero did not fracture even after $10^5$ cycles (even with Hero do not present a real radial land). In the present study, files with radial lands appeared to have fewer striations than those without them.

Cheung & Darvell (2007) also tested cyclic fatigue with 25/.06 Profile instruments. Just by reducing its curvature, files raised its cycles until breakage of 100 to 100000. As the cyclic fatigue exists only in curved canals (more than 35 degrees), the torsional failure is much more important to understand. Unfortunately, almost all studies are focused on flexural fatigue. As the great majority of the teeth are low curved ones, the sequence has a great role on enlargement distribution, decreasing torsion. Root Canal M.A.P.E.R. has shown itself as an important tool to better understand the file load per millimeter in any instrumentation sequence, without considering severe curvatures.

According Tripi *et al.* (2006), Cheung *et al.* (2005), Fife *et al.* (2004), Wei *et al.* (2007) and Cheung & Darvell (2007), avoiding curvatures, low rotation and low flexible files on curvatures, combined with axial oscillation and faster usage of instruments will prevent flexural fatigue failure. As well as increasing critical diameters, low torque values and axial oscillation with pecking motion will also prevent premature torsional failure.

Another important question to discuss is the sterilization cycles. A high number of reutilizations will lead to the need of a high number of cycles. Valois *et al.* (2008) found increased depth of surface irregularities in GT and ProFile NiTi files after 5 or 10 autoclave cycles. But Plotino *et al.* (2012) showed that 10 cycles of sterilization did not reduce fatigue cycles until fracture of K3, MTwo and Vortex instruments. Only the new K3 XF appeared to last longer after these cycles. Probably, because of its “R” phase treatment. King *et al.* (2012) tested if the sterilization cycles affected files torsional toughness. TF files did not suffer any losses on the torsional moment, but presented an increase in the rotation degree angle until fracture, which shows a reduction on fracture possibilities, also probably because of its “R” phase treatment, as K3 XF. GT X files presented a reduction of necessary torque to fracture after 3 or 7 autoclavation cycles, with easier fracture possibilities. Casper *et al.* (2011), who also tested torsional resistance of TF, Vortex and a Controlled Memory NITI file, showed results without differences in torsional resistance after 7 cycles of sterilization. These studies presented that the NITI files are not quite affected by the sterilization cycles at all, permitting them to be highly reutilized. Indeed, our study did not sterilize any instruments, and it could be a limitation, despite of the resistance of NiTi instruments to sterilization cycles.

Our regression results showed some influence between both area and pressure of critical section with the number of uses until fracture in 2 of the 3 test groups. This was an important finding which higher critical area section and lower pressure means higher number of uses at all.

Therefore, the importance is on the load distribution among file first millimeters. The chosen sequence has to be balanced to decrease greater loads from file tips, distributing them through four, five or more millimeters. This way, as the tensioned portion of file (the last active section) gets larger, it will be more torsion resistant too. Apparently, the larger the taper, the larger the last active file section (more torsional resistant), but also less resistant to fatigue cycle, being indicated only to straight or low curvature root canals as seen in this study.

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Table 1 - Group 1 - K3 RS6 sequence fragment size, fractured and critical diameters, number of uses of each file, mean area, force and pressure of the critical section. Bars (/) separate the results of each file tested. Value in parenthesis shows standard deviation.

| **File** | **30/.06** | **25/.10** | **15/.04** | **15/.06** | **20/.06** | **25/.06** |
|---|---|---|---|---|---|---|
| Fragm. (mm) | 4/5 | 3/4 | 3/4 | 5/6 | 4/6 | 4/5 |
| Fracture Ø | **54/60** | 55/65 | 27/**31** | **45/51** | 44/56 | 55/49 |
| Critical Ø | **42 a 57** | 85 a 105 | **29 a 35** | **45 a 60** | 65/71 | 76/85 |
| Uses | 121/102 | 166/147 | 56/100 | 114/106 | 103/117 | 92/96 |
| Mean Area ($10^{-2}$ $mm^2$) | 14.98 (±3.36) | 35.64 (±5.9) | 6.61 (±1.22) | 16.58 (±4.82) | 28.02 (±3.49) | 39.31 (±6.20) |
| Mean Force (N) | 32.68 (±3.75) | 33.87 (±2.84) | 37.34 (±3.65) | 39.00 (±5.56) | 35.36 (±2.2) | 34.89 (±2.76) |
| Plain Shear Pressure (MPa) | 232.83 (±80.25) | 98.28 (±24.68) | 586.66 (±175.46) | 255.11 (±105.03) | 127.69 (±23.78) | 90.43 (±21.27) |
| Torsional Shear Pressure (MPa) | 465.67 (±160.50) | 196.56 (±49.36) | 1173.32 (±350.92) | 510.23 (±210.05) | 255.39 (±47.56) | 180.86 (±42.54) |

Table 2: Group 2 - ProTaper sequence fragment size, fractured and critical diameters, number of uses of each file, mean area, force and pressure of the critical section. Bars (/) separate the results of each file tested. Value in parenthesis shows standard deviation.

| File | SX | S1 | S2 | F1 | F2 |
|---|---|---|---|---|---|
| Fragm. (mm) | 3/4 | 6/6 | 6/6 | 4/5 | 5/5 |
| Fracture Ø | **32.5/39** | **43/43** | 52.8/52.8 | 47.5**/53.5** | 61.5/61.5 |
| Critical Ø | **43.25 a 109** | **43 a 82** | 63 a 89.75 | **50.5 a 75.5** | 74.5 a 84 |
| N° Uses | 44/48 | 44/50 | 42/48 | 55/45 | 43/47 |
| Mean Area ($10^{-2}$ $mm^2$) | 29.38 (±15.57) | 17.26 (±8.27) | 26.05 (±8.83) | 113.65 (±5.2) | 221.62 (±2.87) |
| Mean Force (N) | 47.69 (±21.23) | 48.23 (±8.88) | 37.2 (±6.71) | 45.31 (±9.33) | 34,73 (±2.48) |
| Plain Shear Pressure (MPa) | 368.18 (±405.49) | 390.00 (±149.75) | 162.05 (±87.46) | 390.88 (±239.79) | 163.90 (±35.84) |
| Torsional Shear Pressure (MPa) | 736.37 (±810.99) | 780.00 (±299.50) | 324.09 (±174.92) | 781.77 (±479.57) | 327.80 (±71.67) |

Table 3: Group 3 - ProDesign sequence fragment size, fractured and critical diameters, number of uses of each file, mean area, force and pressure of the critical section. Bars (/) separate the results of each file tested. The value in parenthesis shows standard deviation.

| **File** | **35/.10** | **20/.03** | **15/.05** | **22/.04** | **25/.04** | **20/.06** | **20/.07** |
|---|---|---|---|---|---|---|---|
| Fragm. (mm) | 3/3 | 4/5/4/5 | 1/6.5/6 | 4/6 | 5/6 | 5/6 | 6/6 |
| Fracture Ø | **65/65** | **32/35** | 20**/47/45** | **38/46** | **45/49** | 50**/56** | 62 |
| Critical Ø | **45 a 105** | **29 a 35** | **40/45** | **38/46** | **43/51** | **56 a 71** | 86.5/97 |
| N° Uses | 89/80 | 29/49/40/55 | 52/73/69 | 91/101 | 103/99 | 98/105 | 106/97 |
| Mean Area ($10^{-2}$ $mm^2$) | 36.37 (±19.73) | 5.98 (±0.88) | 8.83 (±1.46) | 8.67 (±2.31) | 10.83 (±2.59) | 22.73 (±5.25) | 46.43 (±7,49) |
| Mean Force (N) | 45.33 (±16.33) | 37.67 (±2.8) | 37.78 (±3.14) | 48.04 (±6.45) | 42.86 (±5.16) | 37.86 (±4.6) | 30.65 (±2.47) |
| Plain Shear Pressure (MPa) | 225.65 (±228.58) | 647.03 (±144.54) | 436.99 (±108.06) | 468.19 (±184.72) | 413.11 (±146.34) | 176.50 (±65.10) | 67.25 (±16.18) |
| Torsional Shear Pressure (MPa) | 451.3 (±457.15) | 1294.06 (±289.08) | 873.98 (±216.13) | 936.38 (±369.45) | 826.21 (±292.69) | 353.00 (±130.20) | 134.49 (±33.37) |

Table 4- Mean number of uses until fracture, critical section area, force, plain and torsional shear pressures, per group.

| Group | K3 RS6 | ProTaper | Prodesign |
|---|---|---|---|
| Mean uses | 110 a | 46.6 c | 78.5 b |
| Minimum/Maximum | 56/166 | 42/55 | 29/106 |
| Mean Area ($10^{-2}mm^2$) | 22.49 a (±12.22) | 22.21 a (±12.43) | 22.44 a (±18.57) |
| Minimum/Maximum | 5.28/43.69 | 8..08/51.32 | 4.89/66.61 |
| Mean Force (N) | 34.99 a (±3.92) | 43.50 a (±13.62) | 40.17 a (±10.39) |
| Minimum/Maximum | 28.07/44.44 | 29.35/73.98 | 28.86/71.11 |
| Mean Plain Shear Pressure (MPa) | 230.95 a (±180.20) | 308.41 a (±273.14) | 347.54 a (±245.93) |
| Minimum/Maximum | 70.39/783.08 | 57.02/915.7 | 50.28/835.28 |
| Mean Torsional Shear Pressure (MPa) | 461.9 a (±360.41) | 616,82 a (±546,29) | 695.08 a (±491.88) |
| Minimum/Maximum | 140.78/1566.16 | 114.41/1831.34 | 11.56/1693.15 |

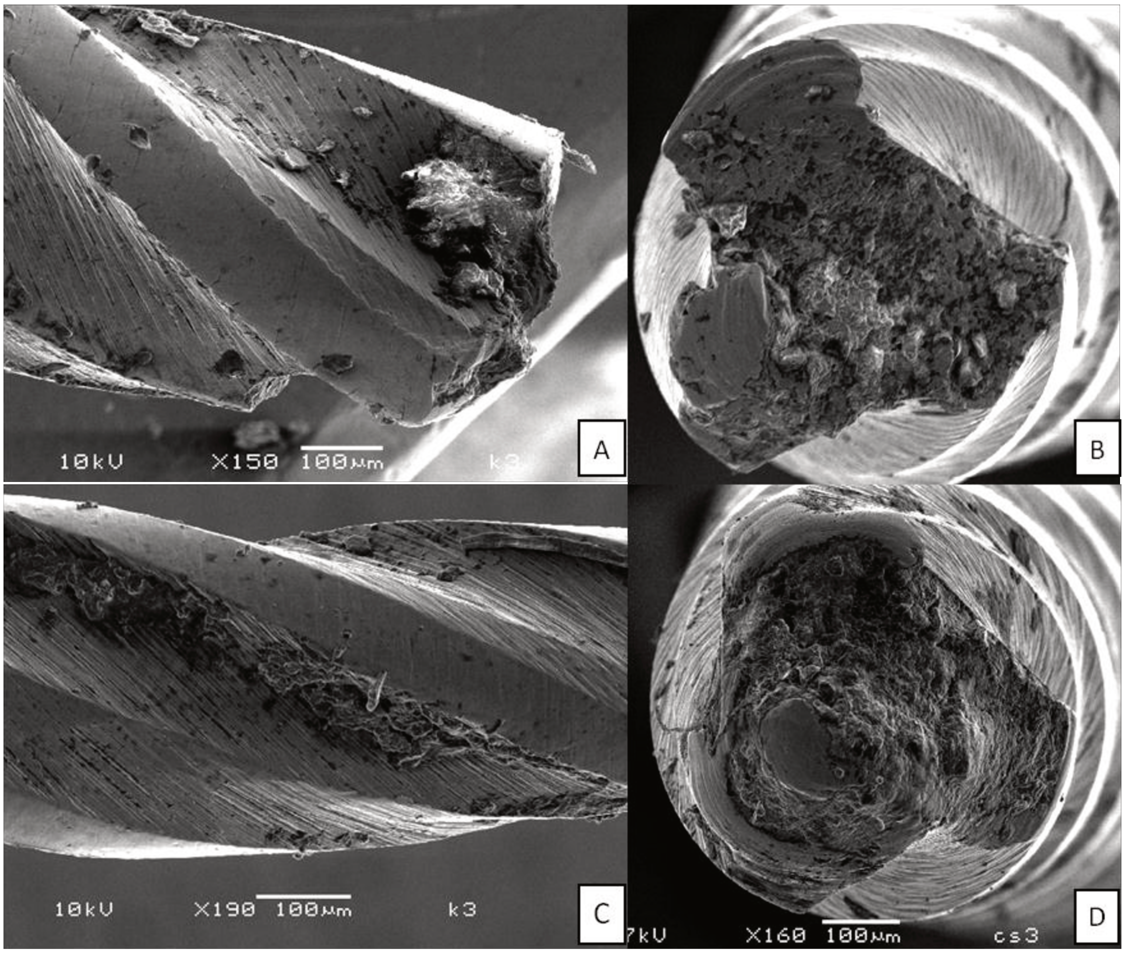
Different letters indicate statistical significant differences in horizontal comparison according to Kruskall Wallis and ANOVA statistical tests ($p<0.05$).

Table 5 – Mean critical section area, force, plain and torsional shear pressures, on the first stroke, per group.

| Group | K3 RS6 | ProTaper | Prodesign |
|---|---|---|---|
| Mean Area ($10^{-2}mm^2$) | 19.51 a (±11.71) | 11.99 a (±5.26) | 14,03 a (±12,58) |
| Minimum/Maximum | 5.28/34.93 | 8.08/18.31 | 4.89/41.14 |
| Mean Force (N) | 39.22 a (±3.06) | 55.32 a (±14.81) | 45.19 a (±12.20) |
| Minimum/Maximum | 36.84/44.44 | 37.6/73.98 | 32.4/71.11 |
| Mean Plain Shear Pressure (MPa) | 314.30 a (±256.66) | 570.91 a (±322.95) | 491.63 a (±254.89) |
| Minimum/Maximum | 105.47/782.08 | 205.3/915.7 | 78.69/846.58 |
| Mean Torsional Shear Pressure (MPa) | 628.59 a (±513.32) | 1141.82 a (±642.56) | 983.25 a (±509.78) |
| Minimum/Maximum | 210.94/1566.16 | 410.56/1831.34 | 157.38/1693.15 |

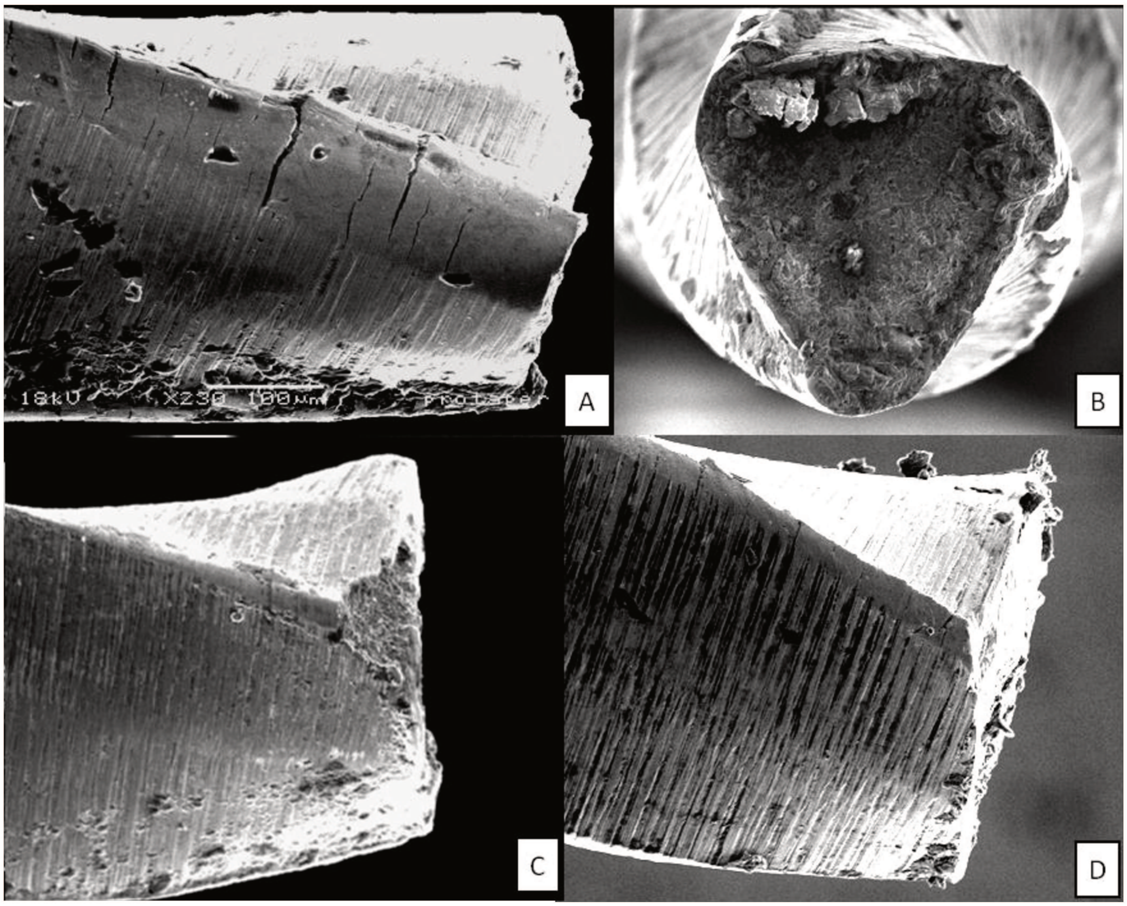
Same letters indicate none statistical significant differences in horizontal comparison according to ANOVA statistical tests ($p>0.05$).

Figure 1 – Factured files in K3 RS6 group.



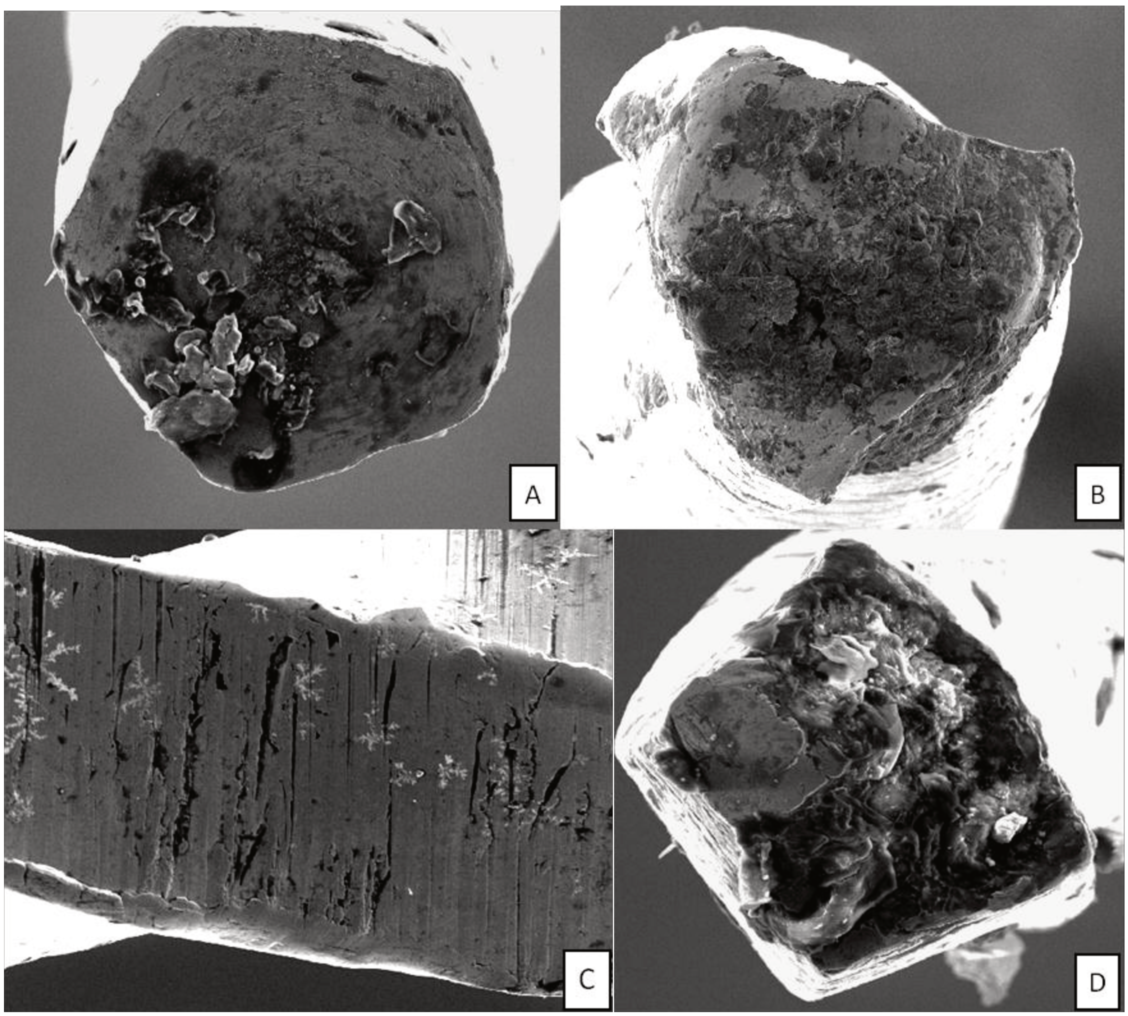

A) K3 15/.06 showing fatigue failure. B) K3 20/.06 cross section view of the fractured part. C) K3 25/.10 integrity of the radial lands. D) K3 25/.06 06 cross section view of the fractured part.

Figure 2 – Factured files in ProTaper group.




A) ProTaper S1 microcracks. B) ProTaper S2 cross section view of the fractured part. C) ProTaper SX separated by flexural fatigue. D) ProTaper F1 microcracks.

Figure 3 – Factured files in ProDesign group.




A) Prodesign # 1 separated by torsion. B) Prodesign # 6 separated by flexural fatigue. C) Prodesign #3 microcracks. D) Prodesign #2 separated by flexural fatigue.

# *Conclusão*

Concluímos que a nova planilha para cálculo matemático da taxa de alargamento de canais radiculares permite um melhor entendimento das forças exercidas ao longo da instrumentação por qualquer sequência de limas, e possibilita a criação de sequências mais seguras quanto à fratura torcional, que pode ocorrer em qualquer tipo de conduto e aparentemente possui grande importância na longevidade dos instrumentos durante as reutilizações.

A planilha apresentou dados condizentes com a fratura das limas, apontando a região de cada lima que mais provavelmente estaria susceptível à fratura em grande parte dos instrumentos testados.

A sequência K3 RS6 mostrou-se extremamente previsível quanto à fratura, alcançando um padrão de longevidade maior quando comparada às outras sequências, apresentando diferenças estatisticamente significantes ($p<0,05$).

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*De acordo com a norma da UNICAMP/FOP, baseado na norma do International Comitee of Medical Journal Editors – Grupo de Vancouver. Abreviatura dos periódicos em conformidade com o Medline.

10/02/2010 Comitê de Ética em Pesquisa - Certificado

# COMITÊ DE ÉTICA EM PESQUISA
## FACULDADE DE ODONTOLOGIA DE PIRACICABA
## UNIVERSIDADE ESTADUAL DE CAMPINAS

# CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa **"Avaliação da longevidade na comparação de sistemas rotatórios de níquel-titânio com uma nova plataforma de análise matemática (M.A.P.E.R.)"**, protocolo nº 189/2009, dos pesquisadores Nilton Vivacqua Gomes e Francisco José de Souza Filho, satisfaz as exigências do Conselho Nacional de Saúde - Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 10/02/2010.

The Ethics Committee in Research of the School of Dentistry of Piracicaba - State University of Campinas, certify that the project **"Evaluation of file longevity on comparison of NiTi rotary systems with a new mathematical analysis platform of enlargement rate (M.A.P.E.R)"**, register number 189/2009, of Nilton Vivacqua Gomes and Francisco José de Souza Filho, comply with the recommendations of the National Health Council - Ministry of Health of Brazil for research in human subjects and therefore was approved by this committee at 02/10/2010.

**Prof. Dr. Pablo Agustin Vargas**
Secretário
CEP/FOP/UNICAMP

**Prof. Dr. Jacks Jorge Junior**
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
Notice: The title of the project appears as provided by the authors, without editing.

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